08/952995

8242

88 Rec'd PCT/PTO 28 NOV 1997

HIGH-VOLTAGE PLANTS WITH ELECTRIC MOTORS

Technical field:

The present invention relates to electric plants comprising motors intended for connection to distribution or transmission networks, hereinafter termed power networks. The invention relates secondly to a motor intended for use in such a plant. The motors may be either synchronous or asynchronous motors.

The plant with electric motors may be a rolling mill, paper mill, pulp drying machine, mine plant, quay structure, fan, pump or compressor systems, hoisting means, traverse, crane, centrifuge, conveyor, workshop plant, steel mills, etc. Plants with electric motors shall thus be understood in their widest sense.

Background art:

The magnetic circuits in electric motors usually comprise a laminated core, e.g. of sheet steel with a welded construction. To provide ventilation and cooling the core is often divided into stacks with radial and/or axial ventilation ducts. For larger motors the laminations are punched out in segments which are attached to the frame of the machine, the laminated core being held together by pressure fingers and pressure rings. The winding is disposed in slots in the laminated core, the slots generally having a cross section in the shape of a rectangle or trapezium.

In multi-phase electric motors the windings are made as either single or double layer windings. With single layer windings there is only one coil side per slot, whereas with double layer windings there are two coil sides per slot. By coil side is meant one or more conductors combined vertically or horizontally and provided with a common coil insulation, i.e. an insulation designed to withstand the rated voltage of the motor to earth.

Double-layer windings are generally made as diamond windings whereas single layer windings in the present context can be made as diamond or flat windings. Only one (possibly two) coil width exists in diamond windings whereas flat windings are made as concentric windings, i.e. with widely varying coil width. By coil width is meant the distance in arc dimension between two coil sides pertaining to the same coil.

Normally all large motors are made with double-layer winding and coils of the same size. Each coil is placed with one side in one

layer and the other side in the other layer. This means that all coils cross each other in the coil end. If there are more than two layers these crossings complicate the winding work and the coil end is less satisfactory.

It is considered that coils for rotating electric motors can be manufactured with good results up to a voltage range of 10 - 20 kV.

Large alternating current motors are divided into synchronous and asynchronous motors, the former generally covering a higher power range up to a few tens of MW and being constructed to be supplied with a voltage of normally maximally 20 kV. The synchronous motor operates with a rotor speed that is synchronous with the network frequency. In an asynchronous motor the magnetic field rotates faster than the rotor so that the induced currents will provide torque in the direction of rotation. The two types of motors are to a great extent similar in construction. They consist of a stator with a rotor placed inside the stator. The stator is built up of a laminated core with slots punched out for the winding. The stator is placed in a bottom box attached to the foundation by its feet. The rotor is suspended in bearings mounted on the box. A stator shell is placed on the bottom box to protect the active parts. The shell is provided with openings for cooling air to enter.

The function of an alternating current motor is based on interaction between magnetic fields, electric currents and mechanical motion. The magnetic fields are localized primarily in the iron of the machine and the electric currents are localized in the windings.

A distinction is made between two main types of alternating current motors: synchronous and asynchronous machines. The principal difference between synchronous and asynchronous machines is how the torque is produced. A synchronous motor is excited by supplying energy to the rotor from the outside via brushless exciters or slip rings, whereas an asynchronous motor obtains its excitation energy from the stator current through induction. The speed of the synchronous motor is therefore not as dependent on load as in the asynchronous motor.

Depending on the construction of the rotor, there are two types of synchronous motors: those with salient poles and those with a cylindrical rotor. In high-speed 2-pole operation the mechanical stresses on the rotor will be extremely high and in that case it is favourable to use a cylindrical rotor. For motors with lower speeds, four-pole or more, the rotor diameter will be larger. In

view of the lower speed and thus correspondingly lower mechanical stresses, it is more favourable for the rotor to have salient poles.

The boundary between the two types is indefinite. At higher power and with four poles, cylindrical rotors are used that are long and slim in shape. At lower power and with four poles, rotors with salient poles are used.

Asynchronous motors are also divided into two types: squirrel-cage induction motors or slip ring motors. Common to both types is that the rotor is built up of laminations with slots for the rotor winding. The difference is in the construction of the winding. The squirrel-cage induction motors have a squirrel-cage winding consisting of axial rods that are short-circuited at the ends with a short-circuiting ring. Asynchronous motors with slip rings have a three-phase winding in the rotor with phase terminals connected to the slip rings.

By designing the rotor slots in various ways the start and operating properties of the squirrel-cage induction motor can be adjusted to various operating requirements. Slip-ring asynchronous motors are primarily used under difficult starting conditions. External resistance can be connected via the slip rings. By increasing the rotor resistance the maximum torque can be moved towards lower speed, thus increasing the start torque. When starting is complete the external start resistance is short-circuited.

The choice of a large alternating current motor as regards to type, nesting class and cooling method, is dependent on the following factors, among others:

- Torque characteristic of the load
- Type of load and load cycle
- Start power restrictions
- Network characteristics
- Cost of electric energy
- Environment where the motor is to be installed
- Investment cost in relation to the estimated service life of the plant

The main desire for an electric machine is that its capital cost and running costs shall be as low as possible. It is therefore desirable to keep the efficiency as high as possible at given power

factors. The synchronous motor generally has higher efficiency than the asynchronous motor.

The rotor of a synchronous motor is often manufactured with salient poles. Its main use is in the power range of 1 MW to a few tens of MW, e.g. for grinding mills and refiners in the paper industry, for large pumps both in the process industry and in connection with weak networks, e.g. for irrigation installations in desert countries. The oil industry also uses large synchronous motors for pumps and compressors.

The main reason for using synchronous motors instead of the less expensive asynchronous motors is that the synchronous motor produces less stress on the network, in the form of lower start current, and that at over-excitation the synchronous motor can also be used to improve the power factor. Large synchronous motors may also have slightly higher efficiency than equivalent asynchronous motors.

The winding must be insulated, both between the winding turns in the coil and also between coil and surroundings. Various forms of plastic, varnish and glassfibre material are often used as insulating material. The coil ends are braced in order to counteract the forces appearing between the various coils, particularly at short-circuiting.

Motors of the type described above are connected to high-voltage networks of e.g. 145 kV through the use of a transformer which lowers the voltage. The use of a motor in this way, connected to the high-voltage network via a transformer entails a number of drawbacks. Among others the following drawbacks may be mentioned.

- the transformer is expensive, increases transport costs and requires space
- the transformer lowers the efficiency of the system
- the transformer consumes reactive power
- a conventional transformer contains oil, with the associated risks
- involves sensitive operation since the motor, via the transformer, works against a weaker network.

Description of the invention:

An object of the invention is therefore to enable the use of one or more electric motors in a plant which is directly connected to high-voltage supply networks, by which is meant here sub-

transmission and distribution networks without intermediate connection of a transformer.

The benefit gained by attaining the above-mentioned object is the avoidance of an intermediate oil-filled transformer, the reactance of which otherwise consumes reactive power.

~~This object is achieved according to the invention in that a plant of the type described in the preamble to claim 1 is given the special features defined in the characterizing part of this claim, and in that an electric motor of the type described in the preamble to claim 25 is given the special features defined in the characterizing part of this claim.~~

Thanks to the specially produced solid insulation, the motors in such a plant can be supplied directly with a voltage level considerably in excess of what is possible using known technology, and at a voltage that may reach the highest applicable voltages for high-voltage power networks.

The advantage is thus gained that the transformer becomes superfluous, therefore eliminating all the problems touched upon above that are inherent with a plant in which the voltage must be stepped down, as well as other significant advantages. With a plant according to the invention the overload capacity is also radically increased. This may be +100 % for an hour or two, enabling motors with lower rated output to be selected, thereby also saving expense.

Higher output is also obtained through a high voltage on the motors since this is proportional to the voltage squared. The invention thus enables electric motors with higher power to be achieved. The invention thus extends the application area for electric machines to the range 1-300 MW and even enables applications at still higher power levels.

The major and essential difference between known technology and the embodiment according to the invention is thus that this is achieved with a magnetic circuit included in at least one electric motor which is arranged to be directly connected to a high supply voltage via coupling elements such as breakers and isolators. The magnetic circuit thus comprises one or more laminated cores. The winding consists of a threaded cable with one or more permanently insulated conductors having a semiconducting layer both at the conductor and outside the insulation, the outer semiconducting layer being connected to earth potential.

To solve the problems arising with direct connection of electric motors, both rotating and static motors, to all types of high-voltage power networks, at least one motor in the plant according to the invention has a number of features as mentioned above, which differ distinctly from known technology. Additional features and further embodiments are defined in the dependent claims and are discussed in the following.

The features mentioned above and other essential characteristics of the plant and at least one of the electric motors included therein according to the invention, include the following:

- The winding is produced from a cable having one or more permanently insulated conductors with a semiconducting layer at both conductor and sheath. Some typical conductors of this type are PEX cable or a cable with EP rubber insulation which, however, for the present purpose are further developed both as regards the strands in the conductor and the nature of the outer sheath. PEX = crosslinked polyethylene (XLPE). EP = ethylene propylene.

- Cables with circular cross section are preferred, but cables with some other cross section may be used in order to obtain better packing density, for instance.

- Such a cable allows the laminated core to be designed according to the invention in a new and optimal way as regards slots and teeth.

- The winding is preferably manufactured with insulation in steps for best utilization of the laminated core.

- The winding is preferably manufactured as a multi-layered, concentric cable winding, thus enabling the number of coil-end intersections to be reduced.

- The slot design is suited to the cross section of the winding cable so that the slots are in the form of a number of cylindrical openings running axially and/or radially outside each other and having an open waist running between the layers of the stator winding.

- The design of the slots is adjusted to the relevant cable cross section and to the stepped insulation of the winding. The stepped insulation allows the magnetic core to have substantially constant tooth width, irrespective of the radial extension.

- The above-mentioned further development as regards the strands entails the winding conductors consisting of a number of impacted strata/layers, i.e. insulated strands that from the point

of view of an electric machine, are not necessarily correctly transposed, uninsulated and/or insulated from each other.

• The above-mentioned further development as regards the outer sheath entails that at suitable points along the length of the conductor, the outer sheath is cut off, each cut partial length being connected directly to earth potential.

The use of a cable of the type described above allows the entire length of the outer sheath of the winding, as well as other parts of the plant, to be kept at earth potential. An important advantage is that the electric field is close to zero within the coil-end region outside the outer semiconducting layer. With earth potential on the outer sheath the electric field need not be controlled. This means that no field concentrations will occur either in the core, in the coil-end regions or in the transition between them.

The mixture of insulated and/or uninsulated impacted strands, or transposed strands, results in low stray losses.

The cable for high voltage used in the winding is constructed of an inner core/conductor with a plurality of strands, at least two semiconducting layers, the innermost being surrounded by an insulating layer, which is in turn surrounded by an outer semiconducting layer having an outer diameter in the order of 10-250 mm and a conductor area in the order of 40-3000 mm^2.

If at least one of the motors in the plant according to the invention is constructed in the manner specified, start and control of this motor or these motors can be achieved with the start methods, known per se, described by way of example in the literature discussed in the introduction.

According to a particularly preferred embodiment of the invention, at least two of these layers, preferably all three, have the same coefficient of thermal expansion. The decisive benefit is thus gained that defects, cracks and the like are avoided during thermal movement in the winding.

According to another important preferred embodiment of the invention at least one of the motors in the plant has one or more connection voltages.

~~From another aspect of the invention, the object stated has been achieved in that a plant of the type described in the preamble to claim 23 is given the special features defined in the characterizing part of this claim.~~

Since the insulation system, suitably permanent, is designed so that from the thermal and electrical point of view it is dimensioned for over 36 kV, the plant can be connected to high-voltage power networks without any intermediate step-down transformer, thereby achieving the advantages referred to. Such a plant is preferably, but not necessarily, constructed to include the features defined for plants as claimed in any of claims 1-22.

The above-mentioned and other advantageous embodiments of the invention are defined in the dependent claims.

Brief description of the drawings:

The invention will be described in more detail in the following detailed description of a preferred embodiment of the construction of the magnetic circuit of an electric motor in the plant, with reference to the accompanying drawings in which

Figure 1 shows a schematic axial end view of a sector of the stator in an electric motor in the plant according to the invention,

Figure 2 shows an end view, step-stripped, of a cable used in the winding of the stator according to Figure 1, and

Figures 3-7 show examples of different start circuits known per se.

Description of a preferred embodiment:

In the schematic axial view through a sector of the stator 1 according to Figure 1, pertaining to the electric motor or motors included in the plant, the rotor 2 of the motor is also indicated. The stator 1 is composed in conventional manner of a laminated core. Figure 1 shows a sector of the motor corresponding to one pole pitch. From a yoke part 3 of the core situated radially outermost, a number of teeth 4 extend radially in towards the rotor 2 and are separated by slots 5 in which the stator winding is arranged. Cables 6 forming this stator winding, are high-voltage cables which may be of substantially the same type as those used for power distribution, i.e. PEX cables. One difference is that the outer, mechanically-protective sheath, and the metal screen normally surrounding such power distribution cables are eliminated so that the cable for the present application comprises only the conductor and at least one semiconducting layer on each side of an insulating layer. Thus, the semiconducting layer which is sensitive to mechanical damage lies naked on the surface of the cable.

The cables 6 are illustrated schematically in Figure 1, only the conducting central part of each cable part or coil side being drawn in. As can be seen, each slot 5 has varying cross section with alternating wide parts 7 and narrow parts 8. The wide parts 7 are substantially circular and surround the cabling, the waist parts between these forming narrow parts 8. The waist parts serve to radially fix the position of each cable. The cross section of the slot 5 also narrows radially inwards. This is because the voltage on the cable parts is lower the closer to the radially inner part of the stator 1 they are situated. Slimmer cabling can therefore be used there, whereas coarser cabling is necessary further out. In the example illustrated cables of three different dimensions are used, arranged in three correspondingly dimensioned sections 51, 52, 53 of slots 5.

Figure 2 shows a step-wise stripped end view of a high-voltage cable for use in an electric motor according to the present invention. The high-voltage cable 6 comprises one or more conductors 31, each of which comprises a number of strands 36 which together give a circular cross section of copper (Cu), for instance. These conductors 31 are arranged in the middle of the high-voltage cable 6 and are surrounded in the embodiment shown by a part insulation 35. However, it is feasible for the part insulation 35 to be omitted on one of the conductors 31. In the present embodiment of the invention the conductors 31 are together surrounded by a first semiconducting layer 32. Around this first semiconducting layer 32 is an insulating layer 33, e.g. PEX insulation, which is in turn surrounded by a second semiconducting layer 34. Thus the concept "high-voltage cable" in this application need not include any metallic screen or outer sheath of the type that normally surrounds such a cable for power distribution.

Figures 3-7, in the form of basic diagrams, show examples of known start procedures applicable to rotating motors in the plant according to the present invention. The following designations are used in the figures:

U:	High-voltage network	X_t	Transformer impedance
X_n	Network impedance	R:	Reactor
B:	Breaker	X_r	Reactor impedance
M:	Motor	C:	Capacitor
X_m	Motor impedance	X_c	Capacitor impedance